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TUCOP FAILURE THRESHOLD TEST C06R

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HANFORD ENGINEERING DEVELOPMENT LABORATORY
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W. J. Woods (UKAEA)

The C06R test was the sixth single-pin test in the collaborative US/UK PFR/TREAT transient testing program.[1] It was designed to study the mechanism, time and location of cladding failure and first fuel escape in an intermediate channel transient undercooling - overpower accident (TUCOP). It complements the L05[2] and L07[3] tests which studied post failure fuel dispersal in a similar hypothetical accident. The test fuel was a single irradiated driver fuel pin taken from the UK's Prototype Fast Reactor (PFR) after ~4% peak burnup.

The test vehicle was the Westinghouse Handford Company's single pin test loop with flowing sodium coolant, and the test fuel was supported by simulated grid supports in the test train flow tube. Instrumentation was provided to measure inlet and outlet flows, temperatures, pressures and acoustic signals, and the fast neutron hodoscope was used to monitor fuel motion.

The power transient was designed in two parts; a constant power portion (flat-top) and the over-power burst. The flat-top power level and initial test flow were chosen to produce test fuel and cladding temperatures simulating those expected in an LMFBR loss-of-flow accident when the flow has reduced to about 1/3 of its nominal value. The burst then simulated the effect of the overpower pulse produced by LOF driven voiding in an LMFBR with substantial

* Work performed under the auspices of the U. S. Department of Energy.

positive sodium void worth. An unique feature of this test was the use of a temperature signal to initiate the overpower burst at a pre-set outlet temperature, with a maximum allowable flat-top duration as a back up burst initiator. The objective of this was to initiate the destructive burst when coolant conditions were close to boiling, but before actual boiling initiation.

The results of the test are summarized in table 1 and figure 1. The power pulse was triggered at 12.95 s when the outlet temperature was 70°C below the saturation temperature of 1230°K. The transient then proceeded on a period of 0.55 s for 0.6 s when the final fast burst was initiated.

During the flat-top the hodoscope observed a gradual axial expansion of the fuel column which, by 10 seconds, reached about 4 mm (uncorrected for end collar effects). There was no noticeable bowing or sideways displacement of the fuel column at this stage. The first significant phenomenon observed during the burst phase of the test was an apparent further increase in fuel at the top of the column, equivalent to ~5 mm of fuel. This may be due to additional axial expansion or internal motion of molten fuel or both in combination. Next, boiling of the sodium coolant began ~125 ms into the final burst, as indicated by the divergence of the inlet and outlet flows. The resulting test section voiding progressed over the next 105 ms when the fuel pin failed at 13.828 s over a 30 mm zone centered at 80% of the fuel height. The inlet flowmeter signal indicates that dryout was possibly occurring during the 10 ms prior to fuel pin failure. Emerging fuel accumulated in the vicinity of the failure site for about 30 ms and then dispersed upwards. This dispersal was coincident with a sudden expulsion of coolant from both ends of the test section.

It is not yet know whether the accumulation of approximately 5 grams of fuel at the failure site is representative of LMFBR conditions or if the initial ex-pin fuel motion was influenced by the proximity of the flow tube. However, it is significant to note that even with the accumulation of fuel outside the failure site, the in-pin motion of molten fuel to the breach produced a decrease in the net fuel worth. The subsequent upwards dispersal of the accumulated fuel produced an additional drop leading to a total decrease in net fuel worth of ~15%.

Fully detailed analyses of the boiling, voiding cladding failure and fuel motion is not yet complete. However, simplified treatments (indicate that fuel pin failure and initial fuel motions are dominated by conditions produced within the fuel by the power burst and depend only weakly on the coolant behavior for this type of transient.

In summary, the C06R test has produced evidence that both pre and post failure internal fuel motions produce net fuel worth decreases that would help mitigate a TUCOP accident in an LMFBR. Furthermore, the high axial failure location will prevent worth increases even if emergent fuel momentarily accumulates at the failure site before it disperses upward.

References: -

1. The PFR/TREAT Programme: Objectives, Progress and Future Work, C. B. Cowking (UKAEA), et al., Proceedings of the L.M.F.B.R. Safety Topical Meeting, July 23, 1982 - Lyon - Ecully France, Vol. II pp 103-112.

2. "In-Pile Loss-of Flow TREAT Test L05 with Prototype Fast Reactor Fuel", W. R. Robinson et al., Trans. Am. Nucl. Soc. Vol. 46 P 510 (1984).

3. Comparison of L04, L05, and L07; Three Irradiated 7-Pin Bundle TUCOP Tests, A. E. Wright et al., this session.

TABLE 1

SUMMARY OF C06R RESULTS

EVENT DESCRIPTION	TREAT CLOCK TIME (S)
TREAT clock and control computer start	0
Start of power raising	3.9
Flat-top power reached ~ 22 MW (TREAT)	5.2
Axial expansion seen by hodoscope	5 - 10
Start of long period segment of burst	12.95
Change to short period segment of burst	13.55
Further fuel observed at top of fuel column	13.65 - 13.76
Start of coolant boiling and test channel voiding	13.725
Probable dryout	13.820
First fuel escape recorded by hodoscope	13.828
Final flow expulsion begins	13.84
Peak power 1161 MW	13.87
Flow tube failure	13.90
Power at zero	14.00

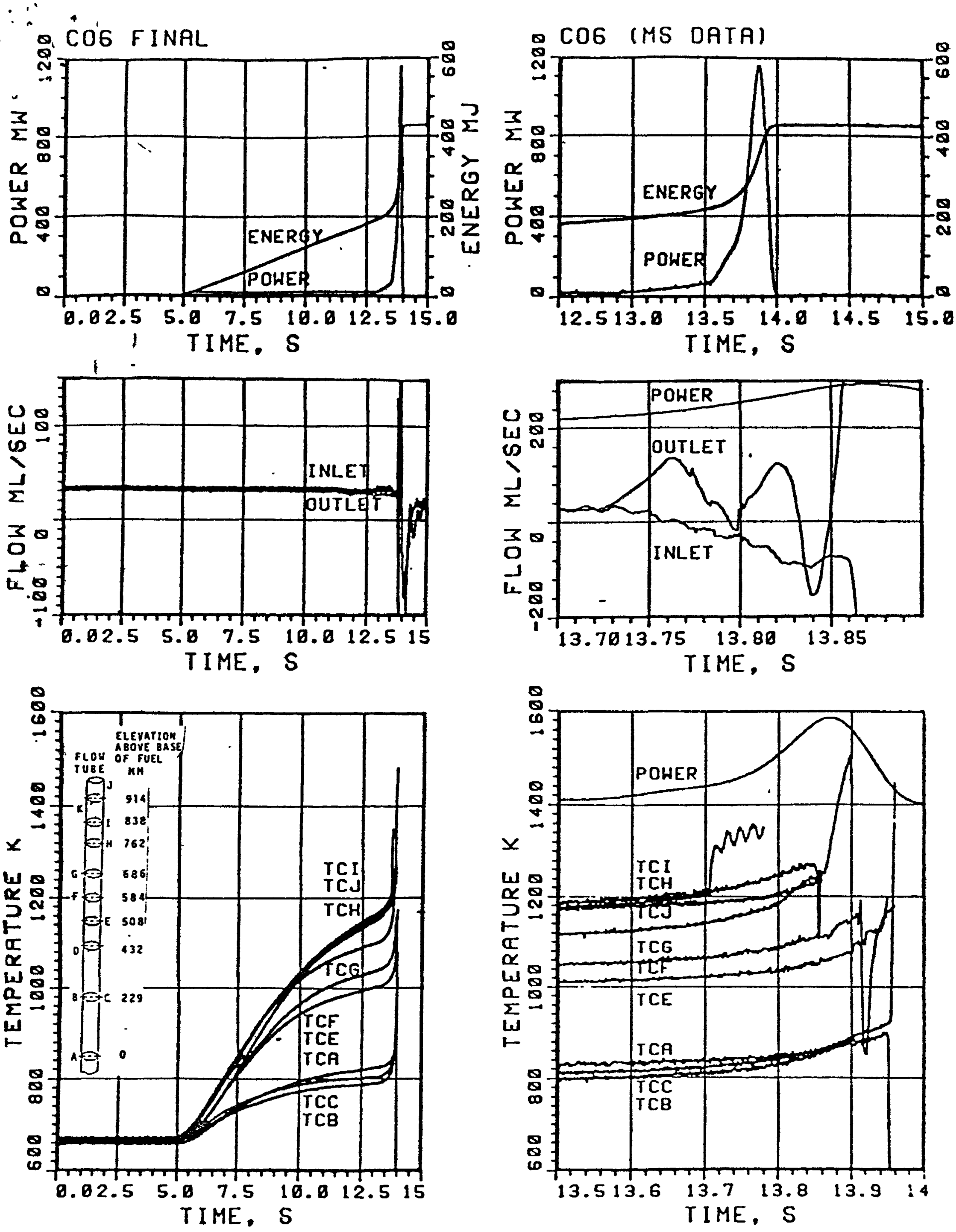

FIGURE 1. C06R - SELECTED RESULTS

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TUCOP FAILURE THRESHOLD

TEST C06R

PRESENTED BY

G. E. Culley

WESTINGHOUSE HANFORD COMPANY

COGR EXPERIMENT OBJECTIVES

- LARGE LMFBR LOSS-OF-FLOW ACCIDENT CONDITIONS - TUCOP
- SIMULATE PART OF CORE UNVOIDED AT START OF OVERPOWER
- ~~STUDY~~ FUEL PIN FAILURE TIME AND LOCATION
- FUEL MOTION TIMING AND QUANTITY

CDGR EXPERIMENT COMPONENTS

- TEST SPECIMEN
  - SINGLE PER FUEL PIN
- THERMAL/HYDRAULIC ENVIRONMENT
  - FLOWING COOLANT PACKAGE LOOP
- NEUTRONIC ENVIRONMENT
  - TREAT FACILITY
- DIAGNOSTICS
  - POWER, FLOW, TEMPERATURE AND FUEL MOTION INSTRUMENTATION

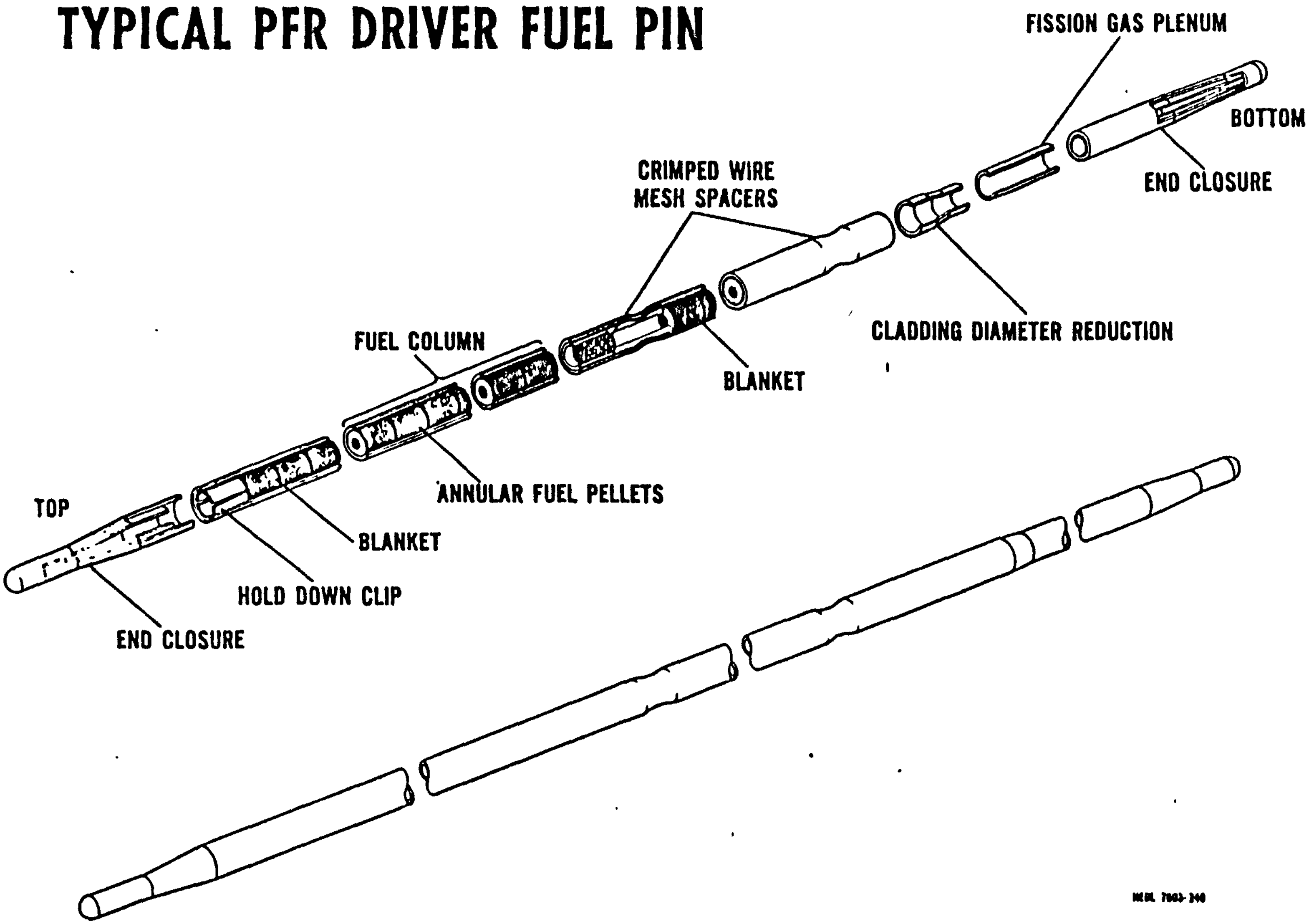


FIGURE 3.1. UK Fabricated PFR Fuel Pin.

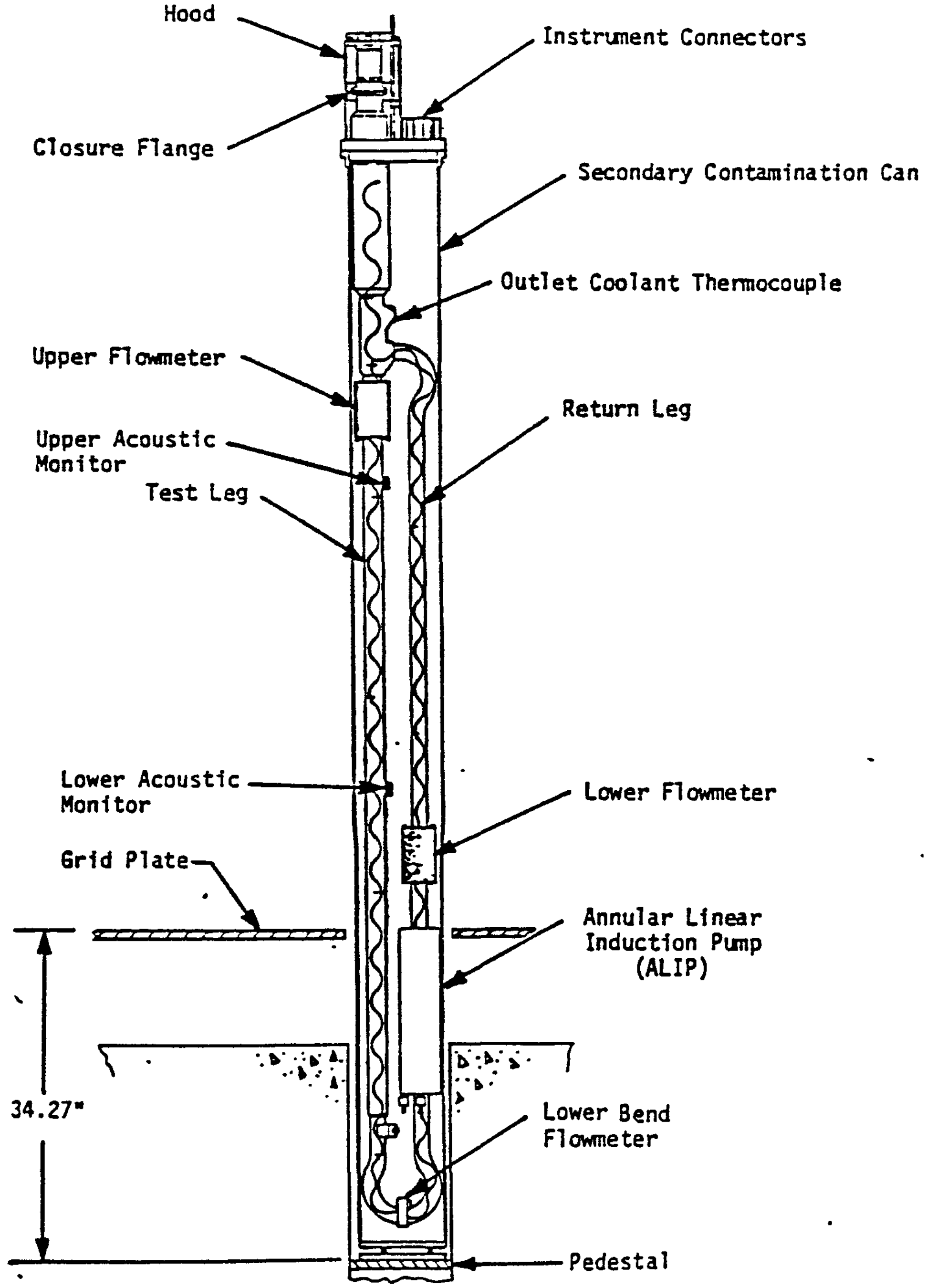


FIGURE 3.2. Single Pin Test Loop Experiment in TREAT - Side View.

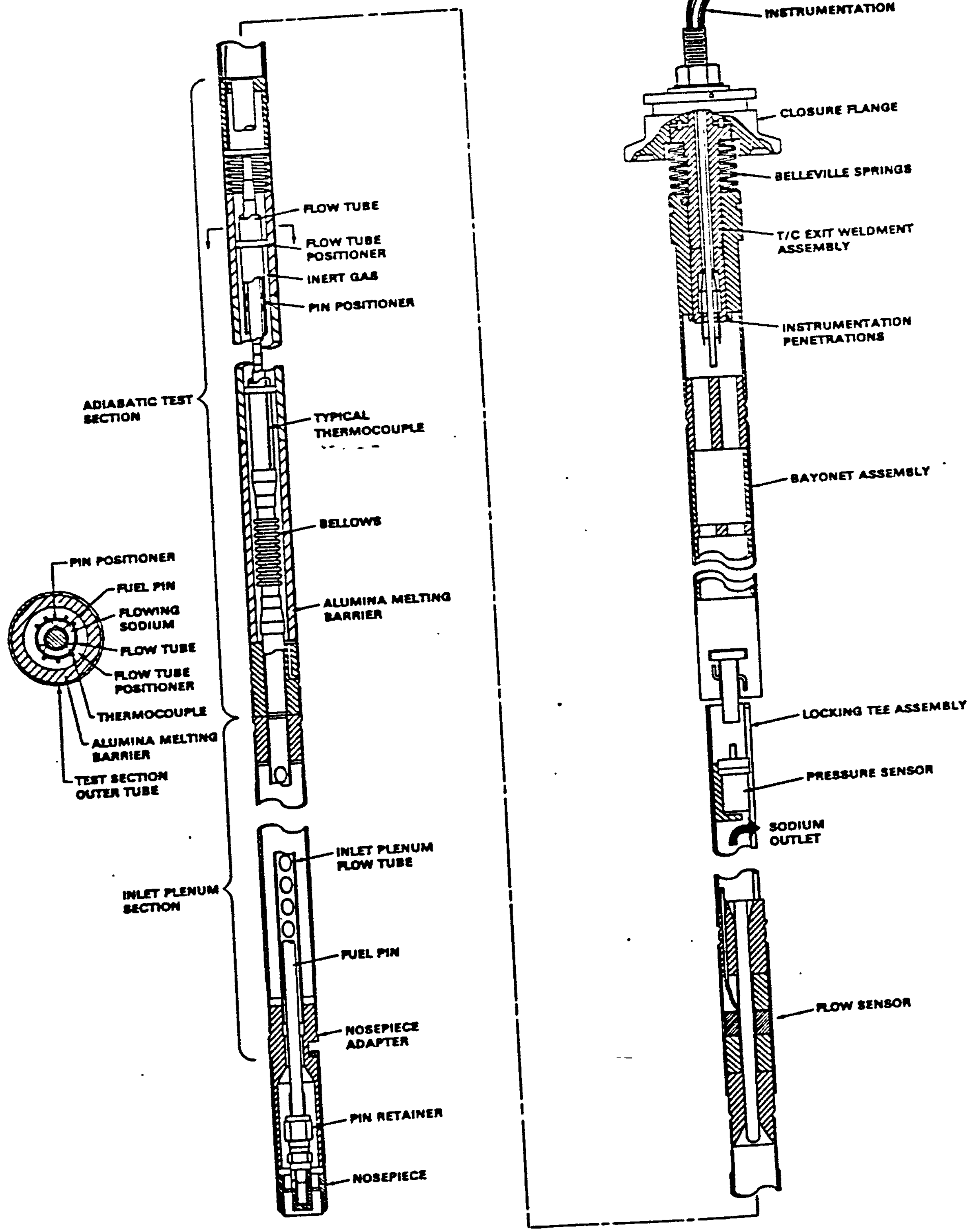
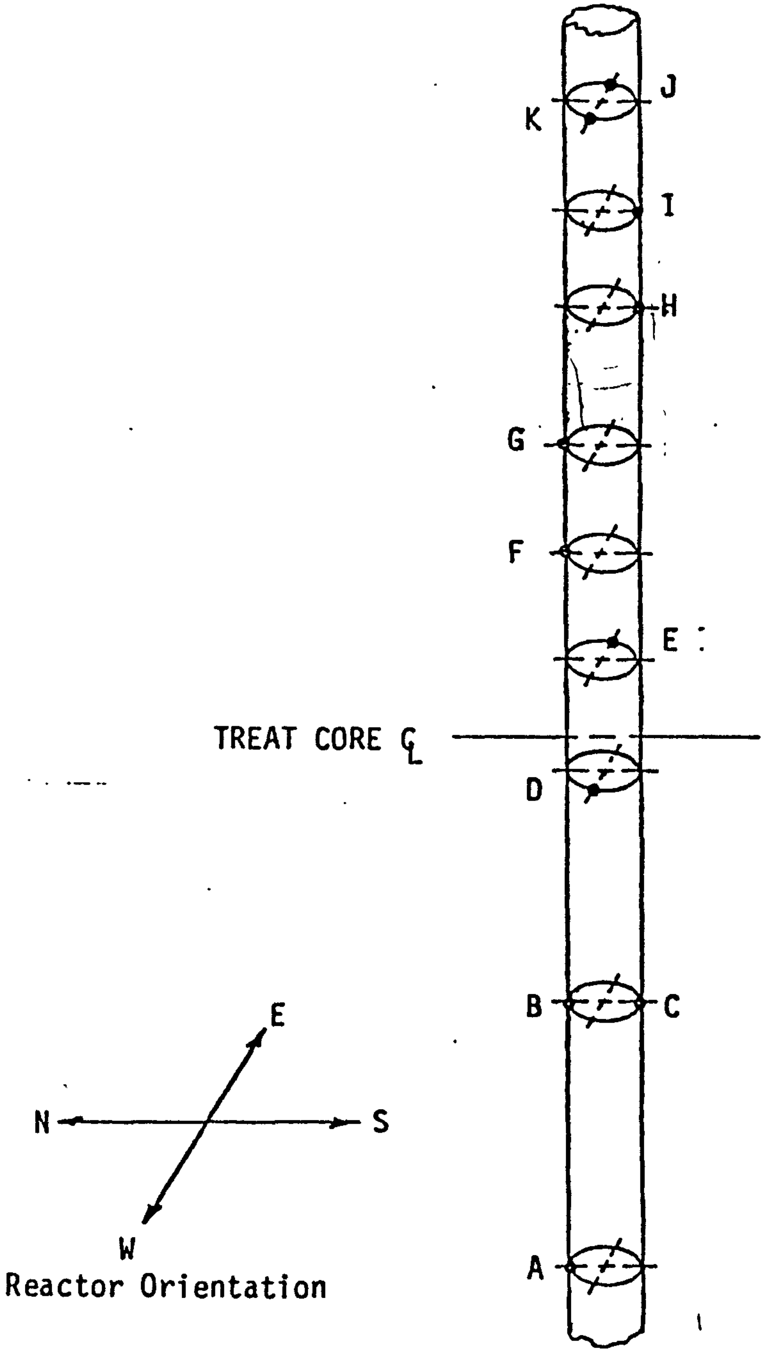
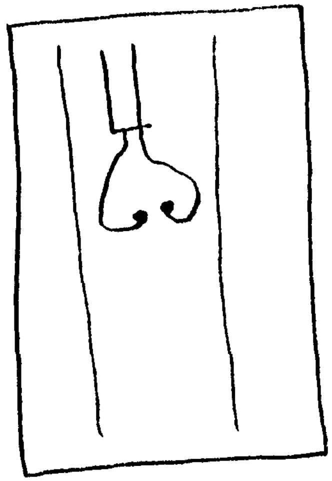


FIGURE 3.3. Single Pin Test Train.

C06R THERMOCOUPLE LOCATIONS



ELEVATION ABOVE BOTTOM OF FUEL COLUMN	
36"	91.4 cm
33"	83.8 cm
30"	76.2 cm
27"	68.6 cm
23"	58.4 cm
20"	50.8 cm
17"	43.2 cm
9"	22.9 cm
0"	0.00cm (BOTTOM OF FUEL COLUMN)



INTRINSIC JUNCTION

COGR EXPERIMENT TEST CONDITIONS

- 1.84 ATM LOOP PRESSURE FIXED BOILING AT 1230K
- LOOP OPERATED AT 670K INLET AND 1/3 FLOW
- TREAT POWER TRANSIENT
  - NORMAL FUEL PIN POWER DURING FLATTOP
  - OVERPOWER INITIATION ON COOLANT TEMPERATURE (1200 K) WITH ENERGY BACKUP
  - TWO STAGE OVERPOWER RAMP
  - TEST TERMINATION AT PRESET OVERPOWER ENERGY DESIGNED TO FAIL PIN

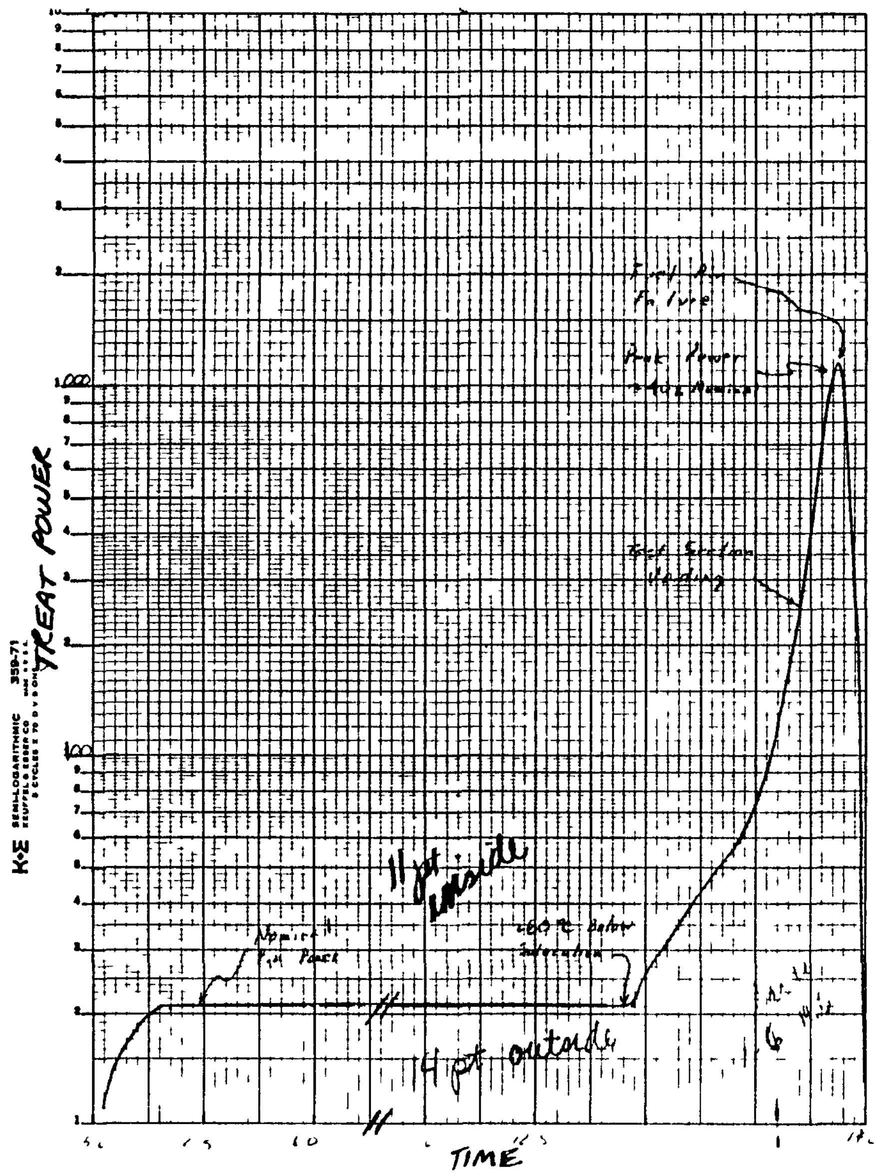
COGR EXPERIMENT CONDUCT

- LOOP, INSTRUMENTATION AND REACTOR SYSTEMS PERFORMED WELL
- OVERPOWER INITIATED ON ENERGY WHEN COOLANT TEMPERATURE 75K BELOW SATURATION
- OVERPOWER ENERGY WITHIN 7% OF DESIGN

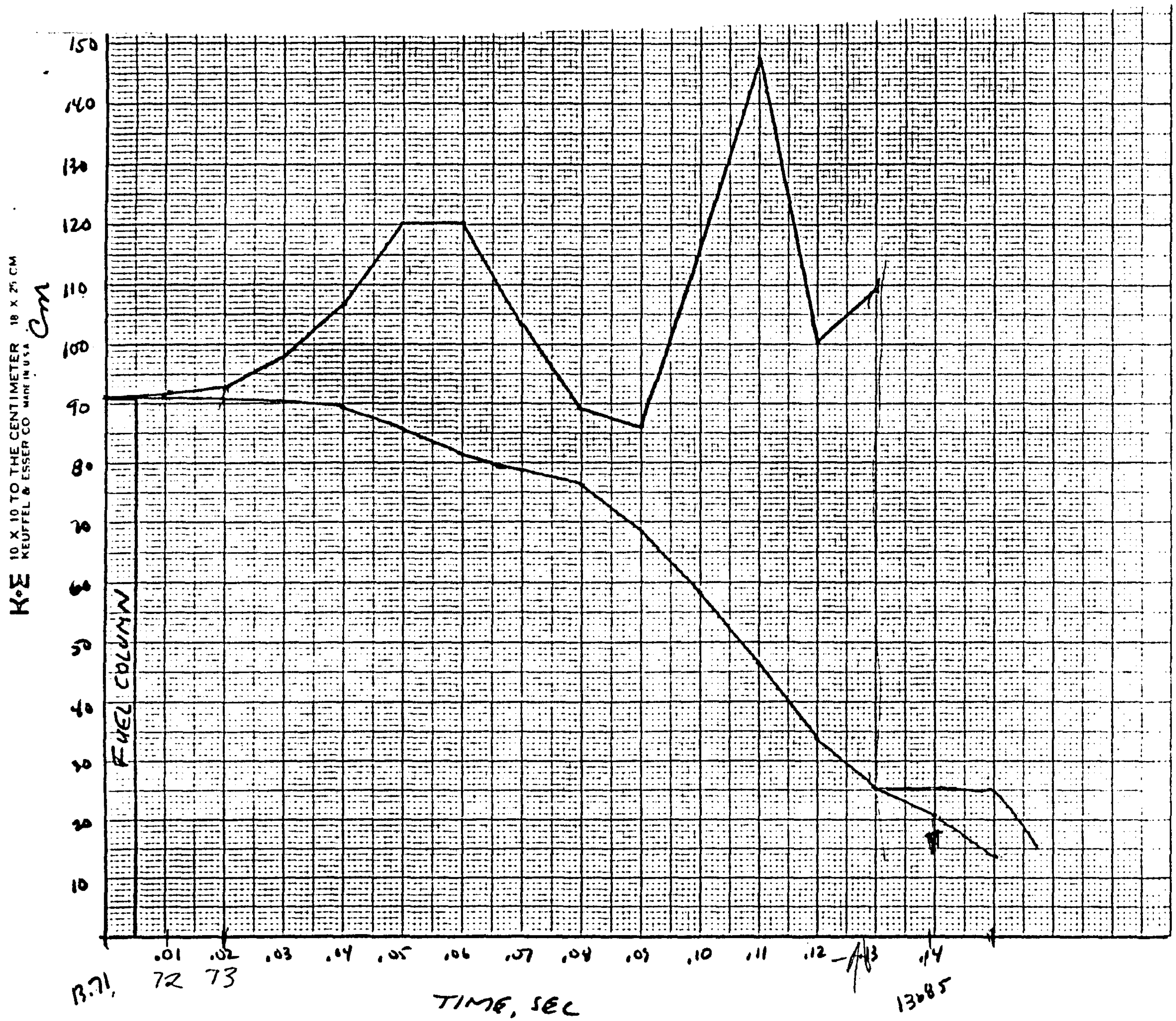
CO6R EXPERIMENT OBSERVATIONS

EVENT	TIME (S)
CLOCK START	0
START POWER	3.9
CONSTANT POWER	5.2 – 12.95
FUEL AXIAL EXPANSION (4 mm)	5 – 10
START OF OVERPOWER	12.95
START OF HIGH RATE OVERPOWER	13.55
ADDITIONAL INTERNAL FUEL MOTION (5 mm)	13.65 – 13.76
START OF VOIDING	13.725
CLADDING FAILURE AND FUEL ESCAPE (5g)	13.828
COOLANT AND FUEL EXPULSION	13.862
PEAK POWER (40 X NORMAL)	13.87

COGR EXPERIMENT KEY EVENTS



106R COOLANT VOID AXIAL PROFILE

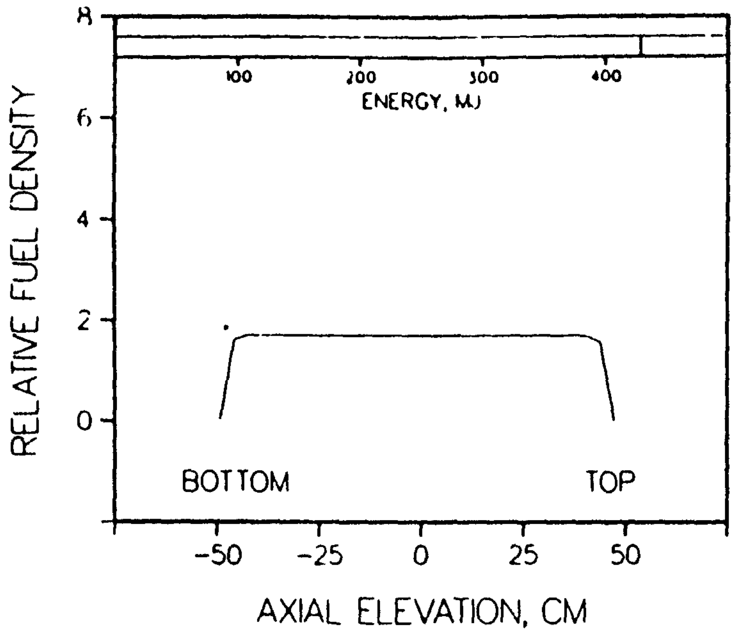


2 Min. Film on Fuel Motion

Highlights follow this page.

AXIAL FUEL DISTRIBUTION
IN THE
HEDL
CO6R EXPERIMENT

7



100
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ENERGY, MJ
RELATIVE FUEL DENSITY
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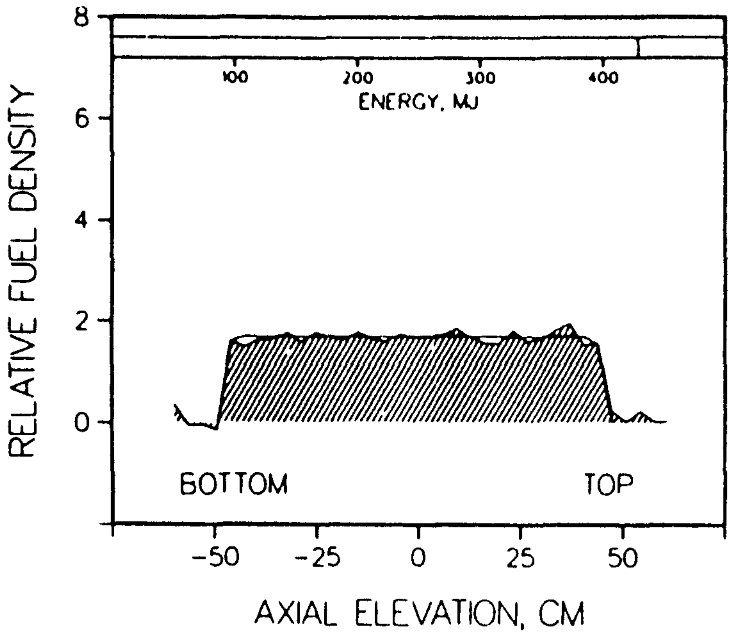
AXIAL ELEVATION, CM



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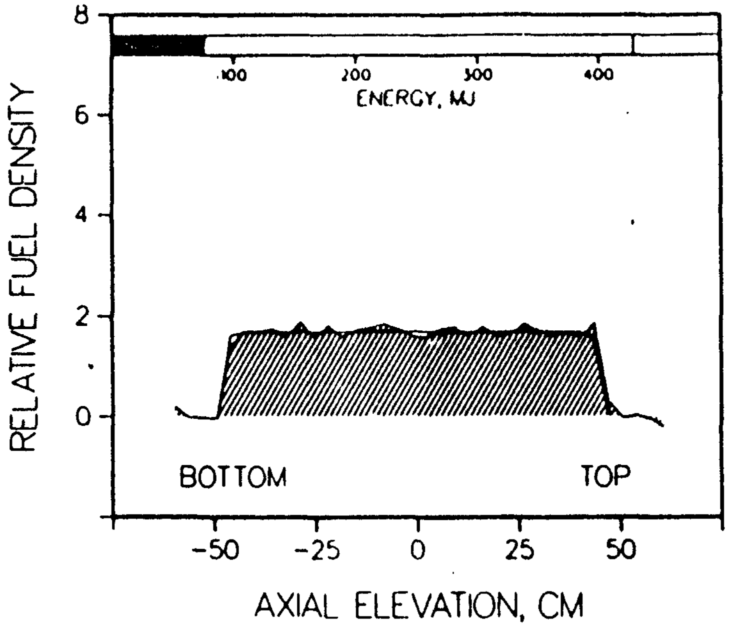

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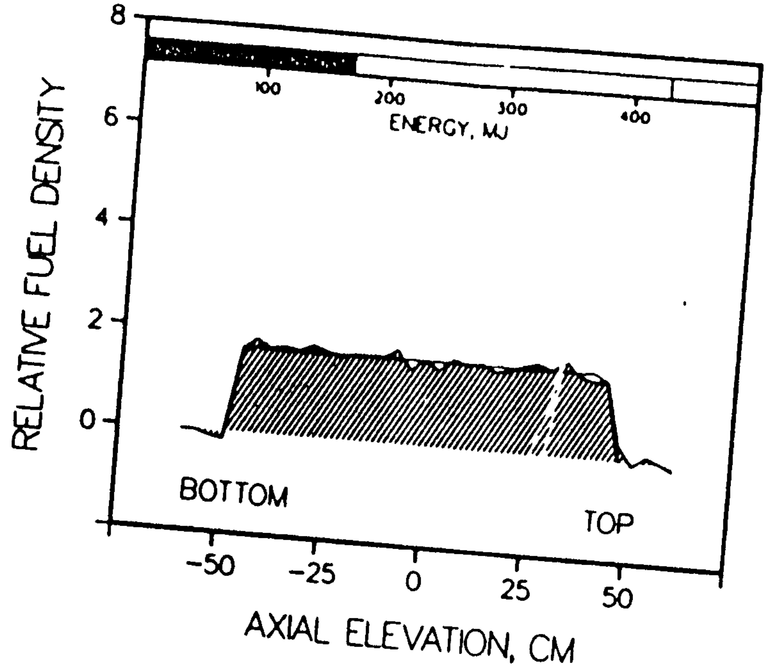
AXIAL ELEVATION, CM



RELATIVE FUEL DENSITY
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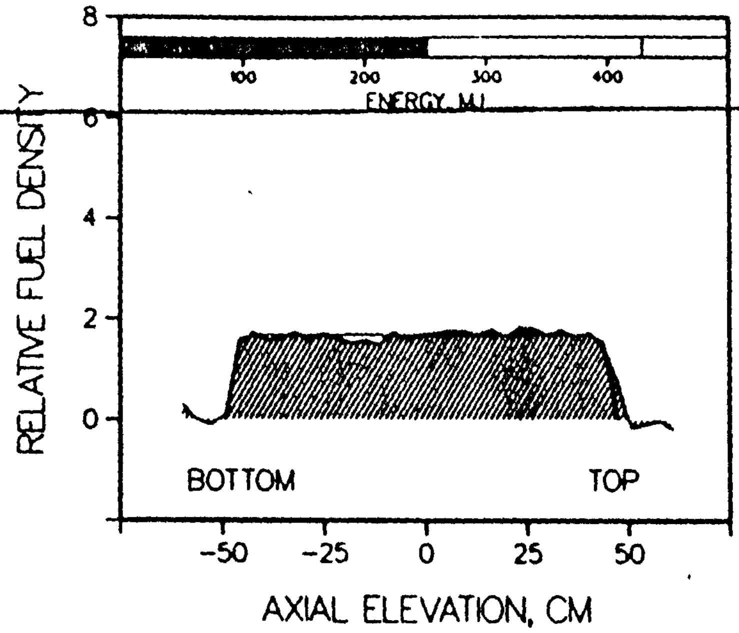

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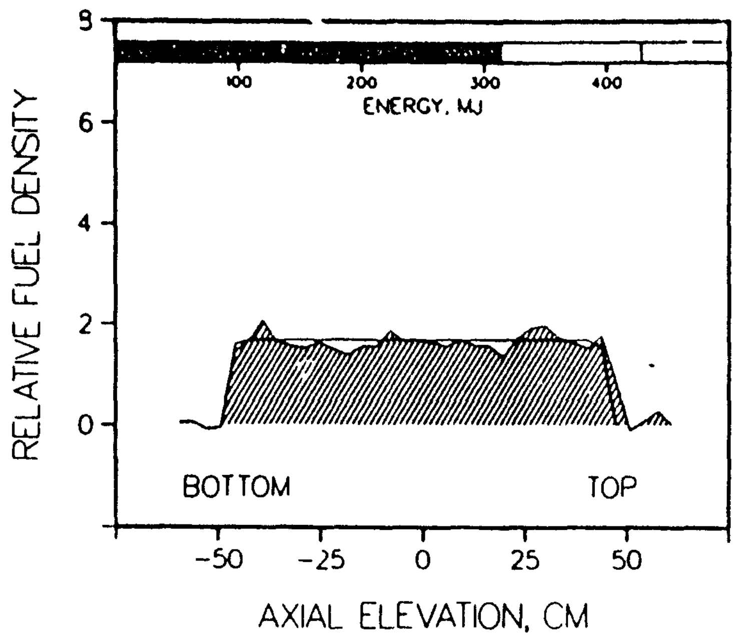

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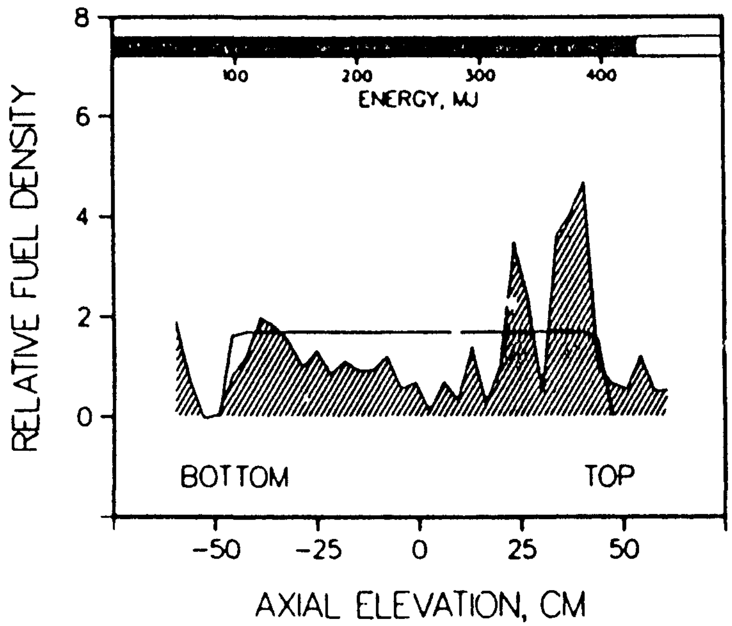

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RELATIVE FUEL DENSITY
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AXIAL ELEVATION, CM

EXPERIMENTER — P. C. FERRELL, HEDL

HODOSCOPE ANALYST — G. S. STANFORD, ANL

FILM BY — R. D. BALDWIN, ANL

COGR EXPERIMENT CONCLUSIONS

- COOLANT VOIDING OCCURS BEFORE FUEL PIN FAILURE
- CLADDING FAILURE DOMINATED BY CONDITIONS PRODUCED BY THE POWER BURST RATHER THAN COOLANT BEHAVIOR
- MOLTEN FUEL EMERGED INTO A VOIDED CHANNEL
- PRE- AND POST- FAILURE INTERNAL FUEL MOTIONS PRODUCE NET FUEL WORTH DECREASES
- SWEEP OUT (spac) IN UPWARD DIRECTION PRODUCES ADDITIONAL WORTH DECREASE

COGR EXPERIMENT IMPLICATIONS IN HCDA ANALYSES

INITIALLY UNVOIDED CHANNEL FUEL PIN RESPONSE ENTAILS SIGNIFICANT FUEL WORTH DECREASES THAT WOULD HELP MITIGATE A TUCOP ACCIDENT IN AN LMFBR